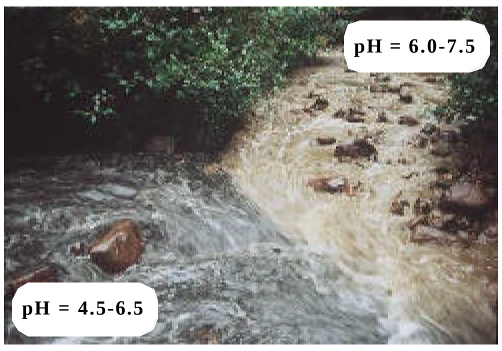
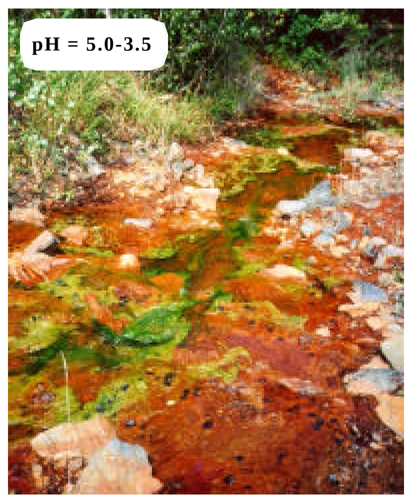
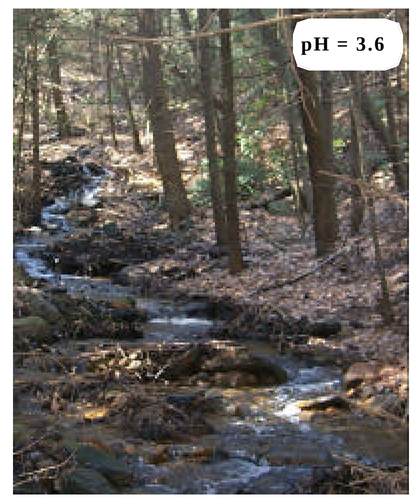
USGS
science for a changing world

WOULD YOU DRINK THIS WATER?

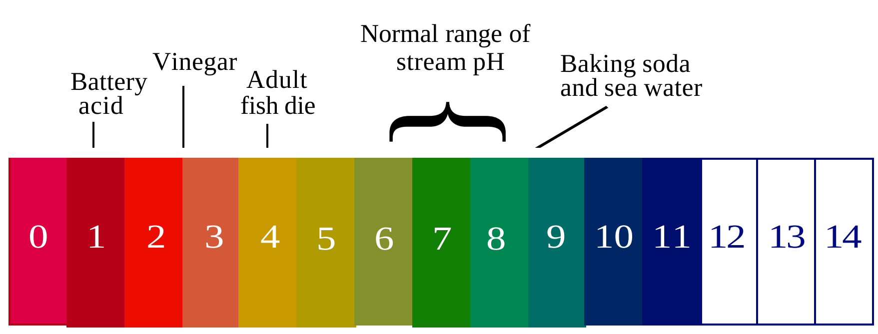






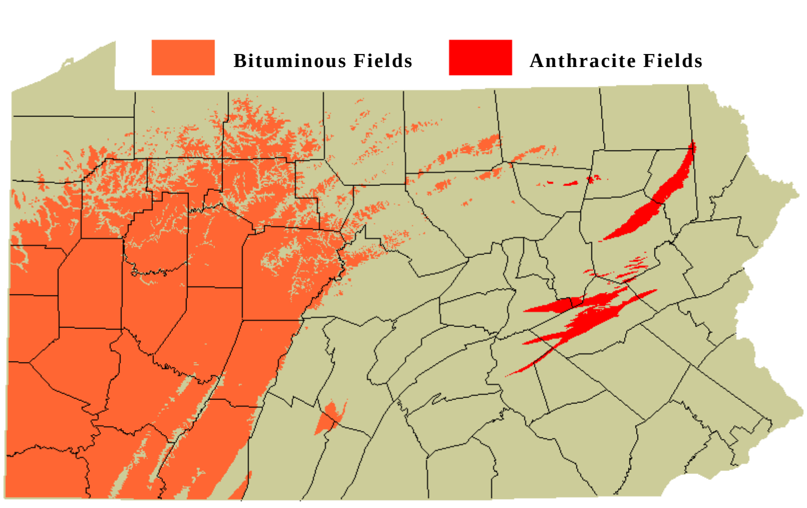
Coal-mine drainage commonly contains elevated concentrations of acidity, sulfate, metals, and sediment. However, not all coal-mine drainage is acidic. Elevated concentrations of acidity (low pH), dissolved minerals, or sediments in coal-mine drainage can be detrimental to aquatic organisms and make the water unfit for most uses.

THE pH SCALE



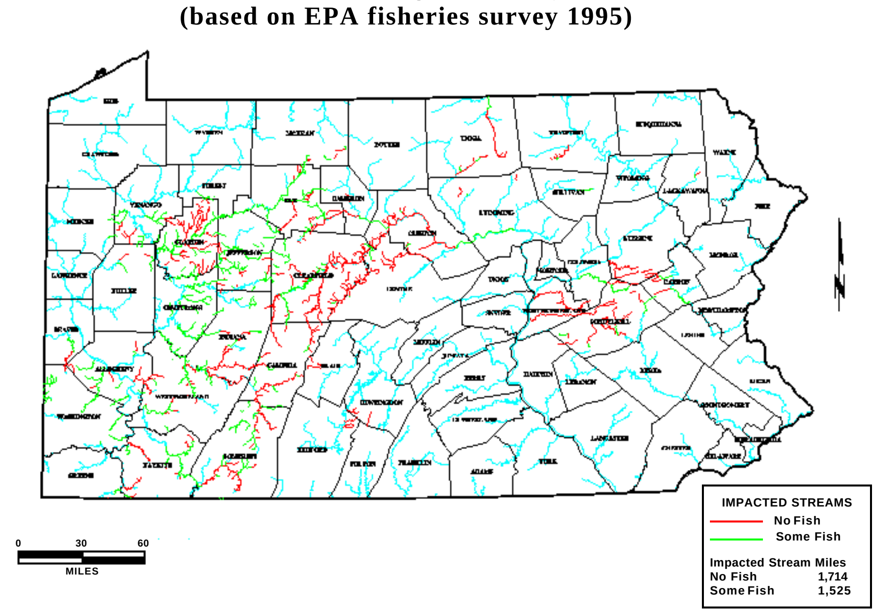
pH measures if a material is acidic or basic. A pH of 7 is neutral. Normal stream water has near-neutral pH. Acidic substances have pH less than 7. Basic, or alkaline, substances have pH greater than 7. Generally, fluids with very low or very high pH can dissolve metals.

Coalfields of Pennsylvania



Coalfields underlie 45 of 67 counties in Pennsylvania encompassing an area of more than 14,000 square miles statewide in the Ohio, Susquehanna, Potomac, and Delaware River Basins. Bituminous coal deposits underlie western and north-central Pennsylvania, and anthracite deposits underlie east-central and northeastern Pennsylvania. Although current Federal and State regulations have been in place since 1977 requiring treatment of contaminated drainage from active mines and reclamation after mining, roughly 1 million acres of abandoned mines continue to cause problems in the Northeastern United States. Environmental problems caused by past coal mining in Pennsylvania represent one-third of all the abandoned mine related problems in the United States.

Streams and Fisheries Impacted by Acidic Mine Drainage in Pennsylvania (based on EPA fisheries survey 1995)



Runoff and drainage from abandoned coal mines in Pennsylvania pollute more than 5,500 miles of streams and associated ground-water supplies. As shown by this map produced in 1995 by the U.S. Environmental Protection Agency, many streams draining the coal-mined areas are fishless or contain few fish. Consequently, Pennsylvania loses approximately $67 million annually because fishing cannot be supported in these streams.

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Photos by Charles A. Cravotta III, U.S. Geological Survey, and Daniel J. Koury, Pennsylvania Department of Environmental Protect ion.

pH OF COAL-MINE DRAINAGE IN PENNSYLVANIA

Pennsylvania was the nation's leading producer of coal through the early 1900's. Presently Pennsylvania is the nation's fourth leading producer of coal, after Kentucky, West Virginia, and Wyoming in order of increasing production. Most coal is burned for electrical generation.

FACTORS AFFECTING pH OF MINE DRAINAGE

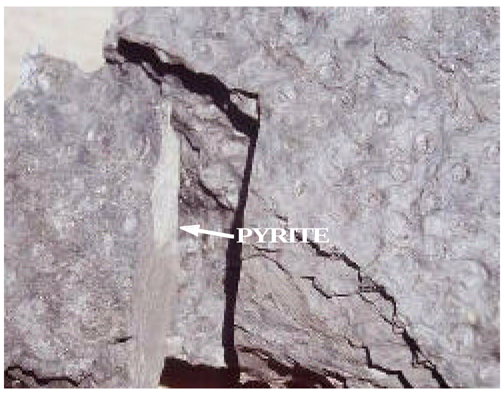
Coal is associated with a variety of rock types. Some of the rocks are acid producing, while others are acid neutralizing. Surface mines tend to disturb all the rock strata overlying the coal (overburden). Underground mines cause localized surface disturbance (subsidence).

ACID & SULFATE ARE PRODUCED BY PYRITE OXIDATION

Overall: $$FeS_2 + 3.75\ O_2 + 3.5\ H_2O \rightarrow Fe(OH)_3 + 2\ SO_4^{2-} + 4\ H^+ \qquad (1)$$

Steps: $$FeS_2 + 3.5\ O_2 + H_2O \rightarrow Fe^{2+} + 2\ SO_4^{2-} + 2\ H^+ \qquad (1a)$$

$$Fe^{2+} + 0.25\ O_2 + 2.5\ H_2O \rightarrow Fe(OH)_3 + 2H^+ \qquad (1b)$$



Oxidation of pyrite (FeS_2) in mined coal and overburden can produce acidic water with high concentrations of sulfate and iron. This water is referred to as acidic mine drainage (AMD). AMD from abandoned coal mines is the largest source of stream water pollution in Pennsylvania.

ACID IS NEUTRALIZED BY LIMESTONE DISSOLUTION

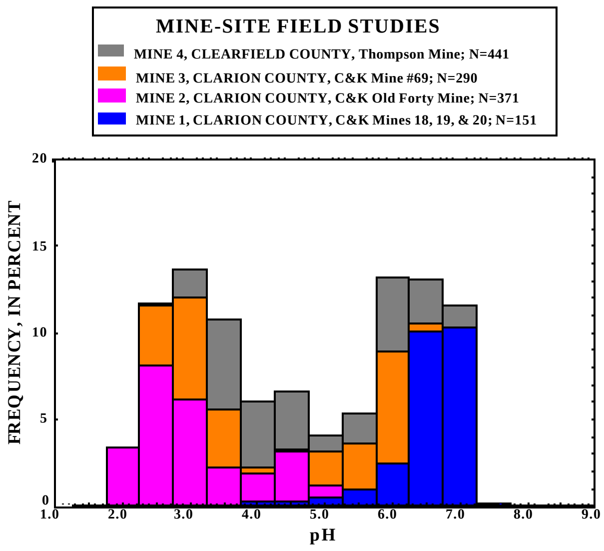
Overall: $$CaCO_3 + H^+ \leftrightarrow Ca^{2+} + HCO_3^- \qquad (2)$$

Steps: $$CaCO_3 + 2\ H^+ \leftrightarrow Ca^{2+} + H_2O + CO_2(aq) \qquad (2a)$$

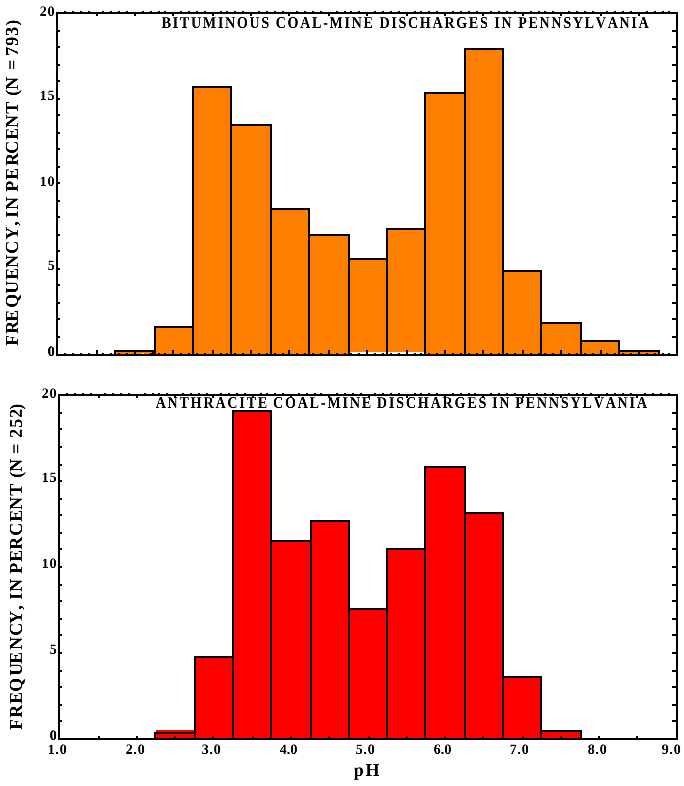
$$CaCO_3 + CO_2(aq) + H_2O \leftrightarrow Ca^{2+} + 2\ HCO_3^- \qquad (2b)$$

Reaction of AMD with limestone ($CaCO_3$) or other calcareous rocks can neutralize acid and increase pH to the neutral range for streamwater. However, the consequent precipitation of iron hydroxide ($Fe(OH)_3$) and aluminum hydroxide ($Al(OH)_3$) can encrust the limestone and reduce its dissolution rate.

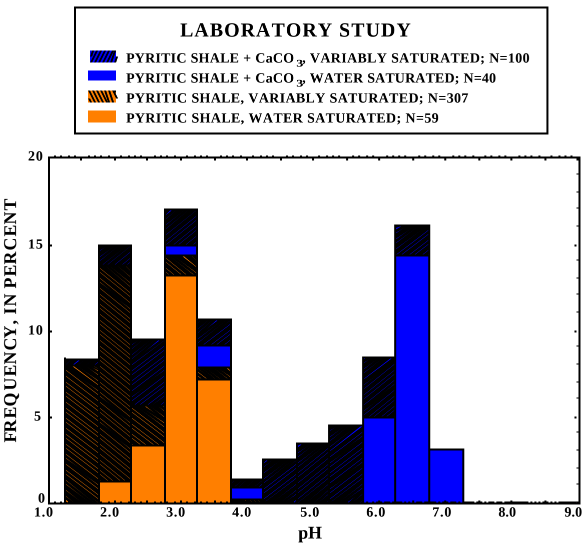
BIMODAL FREQUENCY DISTRIBUTION OF pH



The pH of ground water at a coal mine commonly ranges over several units, and may reflect mainly acidic or alkaline conditions. Ultimately, the ground water may flow to the land surface, thus producing acidic or alkaline drainage from a coal mine. At some mines, the water chemistry for a given discharge or monitoring well can vary from acidic to alkaline depending on the composition and distribution of overburden and the duration and pathways of recharge. Data for each mine were weighted to represent 25% of the total data.



The pH of coal-mine drainage in Pennsylvania has a bimodal frequency distribution; most samples are either distinctly acidic (pH 2.5 to 4) or near neutral (pH 6 to 7), with few samples having pH 4.5 to 5.5. This "bimodal" frequency distribution of pH is apparent for the bituminous and anthracite coalfields of Pennsylvania and also for coalfields in Ohio, West Virginia, Germany, and South Africa. Although many mine discharges have near- neutral pH, the water still can contain elevated levels of sulfate and dissolved iron, manganese, and associated metals. Upon aeration, the pH of metal-laden discharges typically decreases as the dissolved iron oxidizes and precipitates.



Leaching tests showed the bimodal pH distribution for coal-mine drainage results from the weathering of pyritic rock. Without the addition of pulverized $CaCO_3$, the leachate from pyritic shale had pH 1.5 to 3.5 (orange bars) and high concentrations of sulfate and iron. However, with the addition of $CaCO_3$, leachate from this pyritic shale had pH 5.5 to 7 (blue bars) and lower concentrations of sulfate and iron. The tests showed that by maintaining water-saturated conditions, pyrite oxidation and pollutant release were minimized.

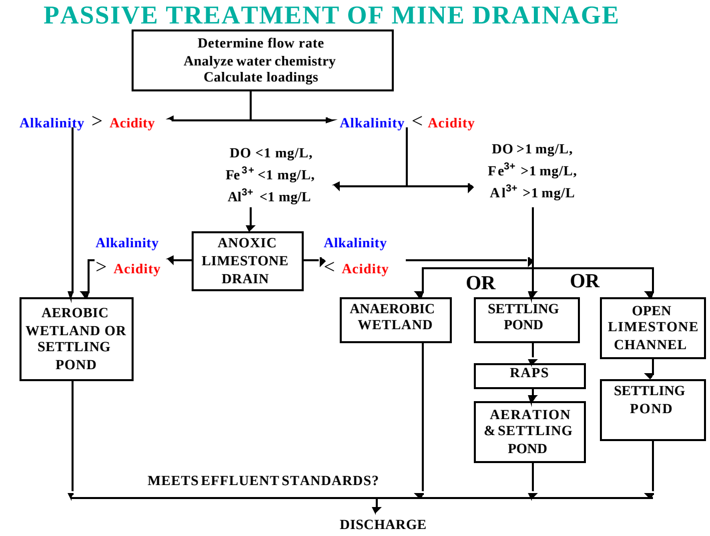
in cooperation with PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL PROTECTION
SCHUYLKILL COUNTY CONSERVATION DISTRICT
U.S. DEPARTMENT OF ENERGY

REMEDIATION OF ACIDIC MINE DRAINAGE

CONVENTIONAL TREATMENT OF MINE DRAINAGE

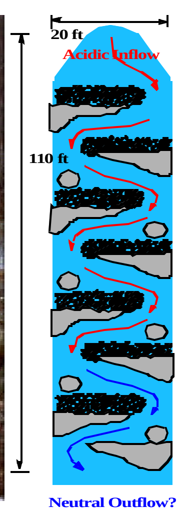
Treatment of AMD may be necessary to neutralize acidity and remove toxic metals. Conventional treatment of AMD typically involves the addition of “alkaline” chemicals to increase pH. Subsequent aeration causes dissolved iron and most other metals to precipitate. The precipitated solids are collected in settling basins. Periodically, sludge is pumped from the settling basins and disposed. Although effective, chemical treatment is expensive and funds to mitigate AMD are limited. Furthermore, the chemical reagents used for neutralization of AMD are dangerous to handle and transport and, if spilled, could cause serious pollution problems.

PASSIVE TREATMENT OF MINE DRAINAGE



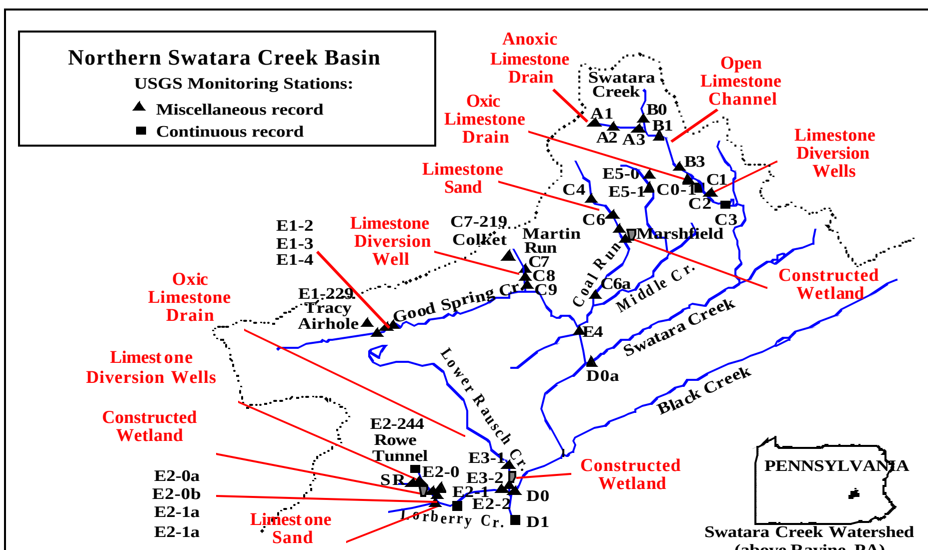
Alternatives for AMD treatment include wetlands and limestone-based systems. These so-called “passive systems” have slower rates of neutralization and pollutant removal than conventional treatments but can be effective where water chemistry meets criteria. Generally, if acidity exceeds alkalinity, treatments including anoxic limestone drains, anaerobic or compost wetlands, reducing and alkalinity producing systems (RAPS), limestone-lined channels, and limestone diversion wells could be used to add alkalinity. If alkalinity exceeds acidity, aerobic wetlands or settling ponds are useful to remove metals.

Open Limestone Channel



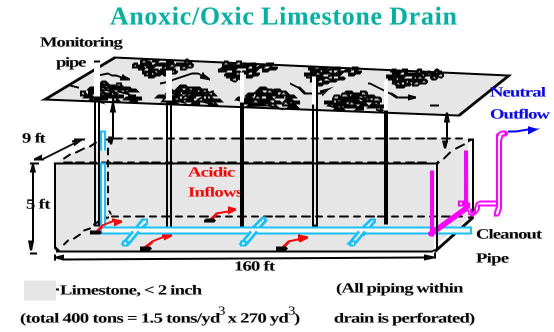
An open limestone channel simply involves lining the streambed with limestone fragments. Slow dissolution rates, encrustation, burial, and transport of limestone from the channel during high flow are concerns. In the acidic headwaters of Swatara Creek, sand-size fragments of limestone were used to promote rapid dissolution, and larger fragments were installed in berms part way across the channel to reduce transport of sand-size fragments and increase longevity of the treatment.

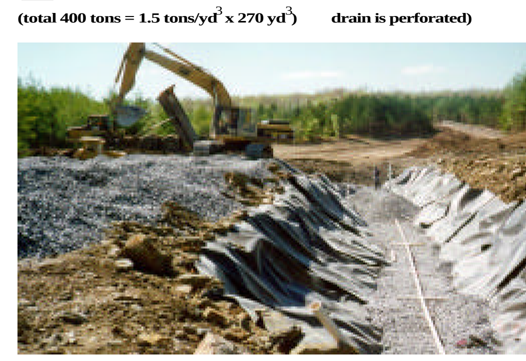
AQUATIC RESTORATION OF A COAL-MINED WATERSHED IN SOUTHERN ANTHRACITE FIELD, PENNSYLVANIA



With a goal of remediating approximately 25 miles of streams degraded by abandoned anthracite mines in the 48 mi^2 northern Swatara Creek Basin, a variety of treatment systems were constructed since 1995 to neutralize AMD. Although several surface and underground anthracite mines presently are active, most mines in the Swatara Creek Basin were abandoned and flooded before 1960. The treatments include an open limestone channel, anoxic and oxic limestone drains, limestone diversion wells, limestone sand dosing, and constructed wetlands. The U.S. Geological Survey (USGS) is evaluating the effectiveness of the treatments over the range of low-flow to high-flow conditions.

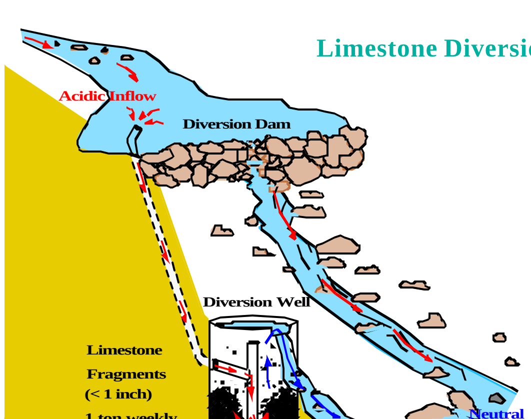
Anoxic/Oxic Limestone Drain





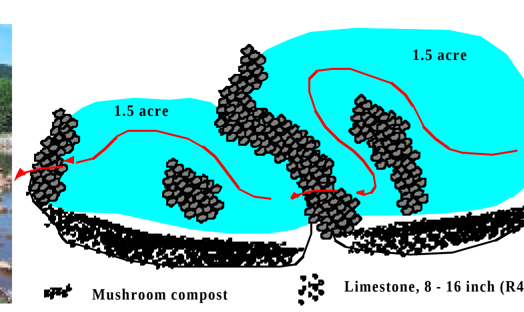
An anoxic limestone drain (ALD) is a relatively simple treatment method where limestone is buried in trenches to intercept AMD before its exposure to air. Keeping oxygen (O_2) out of contact with the water minimizes the potential for oxidation of ferrous iron (Fe^{2+}) and the consequent formation of iron encrustation [$Fe(OH)_3$]. Furthermore, keeping carbon dioxide (CO_2) within the drain enhances limestone dissolution and alkalinity production.

Limestone Diversion Well



In a limestone diversion well, acidic water is diverted from an upstream dam through pipes to a buried tank or “diversion well.” The hydraulic force of the piped flow is deflected upward through a bed of limestone in the well. Churning abrades the limestone fragments forming fine particles, promoting dissolution, and preventing $Fe(OH)_3$ or $Al(OH)_3$ encrustation. Because the limestone bed can be only a few feet thick, diversion wells must be refilled frequently with limestone.

Constructed Wetlands



Constructed wetlands for treatment of mine drainage can attenuate the transport of dissolved and suspended pollutants by promoting the production of alkalinity and the precipitation and deposition of iron and other metals. For net acidic water (acidity > alkalinity), wetlands that have compost and/or limestone substrates can be appropriate. The organic matter in the compost provides a substrate for plant rooting and for microbial reduction of sulfate.